

WHAT IS CLAIMED IS:

1. An apparatus for controlling the movement of a catheter-like tool to be inserted into the body of a patient, comprising:
  - a magnetic field source for generating a magnetic field outside the body;
  - a tool having a distal end responsive to said magnetic field;
  - one or more magnetic sensors to sense a magnetic field produced by said distal end; and
  - a system controller for controlling said magnetic field source to provide a position and command input to control said tool distal end position.
2. The apparatus of Claim 1, said system controller comprising a closed-loop feedback servo system.
3. The apparatus of Claim 1, said distal end comprising one or more magnetic field sensors and one or more temperature sensors.
4. The apparatus of Claim 1, said distal end comprising one or more magnetic field sensors for providing sensor data to said system controller.
5. The apparatus of Claim 1, further comprising an operator interface unit.
6. The apparatus of Claim 1, wherein said servo system comprises a correction input that compensates for a dynamic position of an organ, thereby offsetting a response of said distal end to said magnetic field such that said distal end moves in substantial unison with said organ.
7. The apparatus of Claim 6, wherein said correction input is generated by an auxiliary device that provides correction data concerning said dynamic position of said organ, and wherein when said correction data are combined with measurement data derived from said sensory apparatus to offset a response of said servo system so that said distal end moves substantially in unison with said organ.
8. The apparatus of Claim 7, wherein said auxiliary device is at least one of an x-ray device, an ultrasound device, and a radar device.
9. The apparatus of Claim 1, wherein said system controller includes a Virtual Tip control device to allow user control inputs.
10. The apparatus of Claim 1, further comprising:

a Virtual Tip and Calibration Fixture Controller; and  
a Virtual Tip assembly.

11. The apparatus of Claim 1, further comprising:

an X-Axis controller and amplifier;  
a Y-Axis controller and amplifier; and  
a Z-Axis controller and amplifier.

12. The apparatus of Claim 1, further comprising:

a communication controller;  
a calibration fixture; and  
one or more temperature sensors.

13. The apparatus of Claim 12, wherein said temperature sensors are paired with said magnetic field sensors.

14. The apparatus of Claim 1, wherein said system controller coordinates operation of an X-Axis Controller, a Y-Axis Controller, and a Z-Axis Controller, and wherein said system controller according to inputs from a Virtual Tip.

15. The apparatus of Claim 14, wherein said Virtual Tip provides tactile feedback to an operator.

16. The apparatus of Claim 14, wherein said Virtual Tip provides tactile feedback to an operator according to a position error between an actual position of said distal end and a desired position of said distal end.

17. The apparatus of Claim 14, wherein said system controller causes said distal end to follow movements of said Virtual Tip.

18. The apparatus of Claim 14, further comprising a Virtual Tip/Calibration Fixture Controller that receives encoder position, limit switch, and operator switch data from said Virtual Tip; and

wherein said Virtual Tip/Calibration Fixture Controller outputs a tactile feedback response control to said Virtual Tip.

19. The apparatus of Claim 1, wherein said system controller is configured to calculate a position error of said distal end using at least in part data from said magnetic field sensor and to control said magnetic field source to correct said position error.

20. The apparatus of Claim 1, wherein said system controller initiates a tactile feedback response by providing feedback data to an operator control.

21. A method for controlling movement of a tool having a distal end to be inserted in a body, comprising;

applying a force to said distal end by generating an external magnetic field;  
regulating said force to move said distal end in a desired direction; and  
locating said distal end by measuring a magnetic field of said distal end.

22. The method of Claim 21, further comprising changing a visual representation of said distal end in substantially real time as said distal end moves through the body.

23. The method of Claim 21, further comprising controlling one or more electromagnets to produce said external magnetic field..

24. The method of Claim 21, further comprising measuring a temperature of one or more magnetic field sensors that measure said magnetic field of said distal end.

25. The method of Claim 21, further comprising determining a current position of said distal end in comparison to a desired location.

26. The method of Claim 25, wherein determining said current position of said tool distal end comprises:

inhibiting modulator outputs of a system controller;  
inputting a dynamic cardio position via a communication controller; and  
calculating said current position as a function of said cardio position.

27. The method of Claim 21, further comprising computing a position error of said distal end.

28. The method of Claim 27, further comprising altering at least one of a duty cycle and a polarity of modulation inputs to at least one of said X-axis controller, said Y-axis controller, and said Z-axis controller when said position error is greater than a specified minimum value.

29. The method of Claim 27, further comprising producing a tactile feedback if said position error exceeds a predetermined amount along at least one axis.

30. The method of Claim 21, wherein said system controller causes said tool distal end to move so that its position corresponds to position data from a Virtual Tip.

31. An apparatus for controlling movement of a tool having a distal end to be inserted in a body, comprising;

a magnet source configured in a cluster-like arrangement on a C-Arm forming said closed magnetic circuit and generating a magnetic field;

a tool having a distal end responsive to said magnetic field;

one or more piezoelectric rings disposed about said distal end; and

a system controller for regulating said magnetic field to provide a position and command input to control said tool distal end position.

32. The apparatus of Claim 31, further comprising a closed servo loop system that receives said position and command input from said system controller, to regulate said magnetic force.

33. The apparatus of Claim 32, said distal end comprising one or more magnetic field sensors and one or more temperature sensors.

34. The apparatus of Claim 33, said control system configured to calculate respective torque and associated current for in said magnetic source to configure said magnetic field to move said distal end to a desired location.

35. The apparatus of Claim 34, wherein said closed servo loop circuit includes a correction input that compensates for dynamic position of patient's organs comprising orientation of said tool thereby offsetting said response of said distal end to said magnetic field such that said distal end moves in substantial unison with said organ.

36. The apparatus of Claim 35, wherein said correction input is generated by an auxiliary device that provides data concerning said dynamic position of said organ, and wherein when said data are combined with a set of fiduciary markers forming said stereotactic framing, said position definition measurement data derived from said sensory apparatus, serves to offset a response of said servo system, so that said distal end moves in unison with said organ.

37. The apparatus of Claim 36, wherein said auxiliary device is any one or more of: x-ray, ultrasound, or radar equipment forming said stereotactic frame of reference incorporating position data relative to frame of reference dynamically moving in unison with

said body organs such as cardio output, electrocardiogram and pulmonary expansion and contraction.

38. The apparatus of Claim 31, wherein said system controller includes a Virtual Tip, wherein movement of at least a portion of said Virtual Tip causes the system controller to control electromagnets to move said distal end correspondingly.

39. An apparatus for controlling the movement of a catheter-like tool to be inserted into the body of a patient, comprising;

- a controllable magnetic field source having a first cluster of poles and a second cluster of poles, said first cluster of poles substantially opposed to said second cluster of poles;

- a tool having a distal end responsive to said magnetic field; and

- one or more magnetic sensors to sense a magnetic field produced by said distal end.

40. The apparatus of Claim 39, said distal end comprising one or more magnetic field sensors and one or more temperature sensors.

41. The apparatus of Claim 39, said distal end comprising one or more magnetic field sensors for providing sensor data to a system controller.

42. The apparatus of Claim 39, further comprising an operator interface unit.

43. The apparatus of Claim 39, wherein said first cluster of poles is connected to said second cluster of poles by a magnetic material.

44. The apparatus of Claim 39, further comprising a Virtual Tip control device to allow user control inputs.

45. The apparatus of Claim 39, further comprising:

- a Virtual Tip and Calibration Fixture Controller; and

- a Virtual Tip assembly.

46. The apparatus of Claim 39, further comprising:

- a communication controller;

- a calibration fixture; and

- one or more temperature sensors.

47. The apparatus of Claim 39, wherein said temperature sensors are paired with said magnetic field sensors.

48. The apparatus of Claim 39, further comprising a Virtual Tip that provides tactile feedback to an operator.

49. The apparatus of Claim 48, wherein said Virtual Tip provides tactile feedback to an operator according to a position error between an actual position of said distal end and a desired position of said distal end.

50. The apparatus of Claim 39, further comprising a system controller to control a magnetic field produced by said three-dimensional magnetic field source to cause said distal end to follow movements of a Virtual Tip.

51. An apparatus for generating a magnetic field, comprising;

a first cluster of first electromagnet poles provided to a mass of magnetic material;

a first plurality of electromagnet coils provided to said first electromagnet poles, said first plurality of electromagnet coils controllable on a substantially separate basis;

a second cluster of second electromagnet poles provided to said mass of magnetic material such that said second cluster of second electromagnet poles substantially opposes said first cluster of first electromagnet poles, said magnetic mass completing a magnetic circuit from said first cluster said second cluster; and

a second plurality of electromagnet coils provided to said second electromagnet poles, said second plurality of electromagnet coils controllable on a substantially separate basis such that an orientation of a magnetic field in a region between said first cluster and said second cluster is controllable in multiple dimensions.

52. The apparatus of Claim 51, wherein said first cluster of first electromagnet poles comprises three electromagnet poles.

53. The apparatus of Claim 51, wherein pole faces of said first electromagnet poles lie substantially on a sphere.

54. The apparatus of Claim 51, wherein pole faces of said first electromagnet poles lie substantially on a sphere and where pole faces of said second electromagnet poles lie substantially on said sphere.



55. The apparatus of Claim 51, further comprising a system controller to control electric currents in said first plurality of coils and said second plurality of coils to control said orientation of said magnetic field.

56. The apparatus of Claim 51, further comprising:

a tool having a distal end responsive to said orientation of said magnetic field; and  
one or more magnetic sensors to sense a magnetic field produced by said distal end.

57. The apparatus of Claim 56, said distal end comprising one or more magnetic field sensors and one or more temperature sensors.

58. The apparatus of Claim 56, further comprising a Virtual Tip control device to allow user control inputs.

59. The apparatus of Claim 56, further comprising a Virtual Tip that provides tactile feedback to an operator.

60. The apparatus of Claim 59, wherein said Virtual Tip provides tactile feedback to an operator according to a position error between an actual position of said distal end and a desired position of said distal end.

61. The apparatus of Claim 56, further comprising a system controller to control electric currents in said first plurality of coils and said second plurality of coils to control said orientation of said magnetic field to apply magnetic force to said distal end.

62. A catheter tip assembly, comprising;

a permanent magnet; and

one or more piezoelectric rings.

63. A method for controlling movement of a tool having a distal end to be inserted in a body, comprising;

calculating a desired direction of movement for said distal end;

computing a magnetic field needed to produce said movement;

controlling a plurality of electric currents to produce said magnetic field; and

locating said distal end by measuring a magnetic field of said distal end.

64. The method of Claim 21, wherein said computing a magnetic field comprises:

determining a current position of said distal end with respect to one or more magnet poles; and

using a lookup table to find said magnetic field needed to produce said movement.

65. The method of Claim 63, further comprising controlling one or more electromagnets to produce said external magnetic field..

66. The method of Claim 63, further comprising measuring a temperature of one or more magnetic field sensors that measure said magnetic field of said distal end.